Bellcomm, Inc.

Reference No. 65 2047

C. Stieg Dept 1023

COVER SHEET

Propulsion

CONFIDENTIAL

JUN 2 8 1965

B. P. BROWN
W. P. HICKEY
G. DUNCAN
R. W. MOHR
T. J. McENTEE

UNCLASSIFIED

GDS Cpt
Dicora L. Zeiman 1/2/75

Scientific and Technical Information Facility

FACILITY FORM 602

X66 30197

(ACCESSION NUMBER)

30

(PAGES)

CR 68824

(THRU)

1

(CODE)

18

(NASA-CR-68824) APOLLO SPACECRAFT PROPULSION PERFORMANCE CAPABILITIES FOR SATURN 5 LUNAR MISSIONS AND SIMULATIONS (Bellcomm, Inc.) 30 p

N75-75467

Unclas
00/98 27444

[redacted]

JUL 1975
RECEIVED
NASA STI FACILITY
INPUT BRANCH

CONFIDENTIAL

Form BS-4B (2-65)

SAFEGUARDS

The attached material must not be disclosed to individuals who are not cleared for access to CONFIDENTIAL information. Additional safeguards which must be observed are:

1. During actual use:

   (a) Keep under the constant surveillance of an authorized person.

   (b) Cover, turn face down, place in an approved storage container, or otherwise protect when unauthorized persons are present.

2. When not in actual use:

   (a) Return to the Control Office, or

   (b) Store in an approved locked safe or safe-file, having a three-position dial-type, changeable combination lock, or in a locked steel file cabinet secured by a steel bar and a three-position dial-type changeable combination padlock.

3. Reproduce only when essential to the performance of the contract.

4. Transmit within the company only by appropriately cleared personnel.

5. Removal or transmission from the company must be handled through the Control Office.

6. This Cover Sheet must be handled as classified waste when detached from the material.

Propulsion

CONFIDENTIAL

Ref. No. 65 2047
Copy No. ____ of ____ Copies

BELLCOMM, INC.

SUBJECT: Apollo Spacecraft Propulsion Performance Capabilities for Saturn V Lunar Missions and Simulations (U) - Case 217

DATE: June 14, 1965

FROM: T. R. Kornreich

ABSTRACT

5-0197

The performance capabilities of the Apollo spacecraft in attaining various proposed lunar missions on Saturn V flights prior to the first manned landing were analyzed.

It was found that circumlunar missions can be performed with sufficient ΔV capability remaining to decelerate into a low altitude earth orbit prior to reentry if so desired, even on initial Saturn V flights with payload capability of only 85,000 lbs.

Assuming launch vehicle payloads corresponding to present control weights, unmanned landings of a fully loaded LEM could take place as early as SA-504. Eliminating the CSM chase and rescue ΔV capability would actually leave excess spacecraft performance capability which can be utilized either by increasing the transearth ΔV or landing a heavier than control weight LEM (allowing, e.g., additional instrumentation). In the latter case, however, it would be necessary to reduce the LEM descent ΔV budget. On SA-503 or earlier, the LEM would have to be off-loaded for an unmanned landing.

Alternatively, lunar orbit missions can be performed in which the LEM is retained to provide redundant propulsion capability for the transearth injection. By so doing, earth return can be accomplished even with failure of the SPS after deboost into lunar orbit and prior to transearth injection.

Author

BA-147B (8-64)

GROUP-4
Downgraded at 3 year intervals;
declassified after 12 years

CONFIDENTIAL

This document contains information affecting the National Defense of the United States, within the meaning of the Espionage Laws, Title 18, U.S.C., Section 793 and 794, the transmission or revelation of which in any manner to an unauthorized person is prohibited by law.

BELLCOMM, INC.

SUBJECT: Apollo Spacecraft Propulsion Performance Capabilities for Saturn V Lunar Missions and Simulations (U) - Case 217

DATE: June 14, 1965

FROM: T. R. Kornreich

MEMORANDUM FOR FILE

INTRODUCTION

An analysis of the capabilities of the Apollo spacecraft propulsion systems in satisfying the requirements of various proposed lunar missions during Saturn V flights prior to the first manned landing was performed. Specific missions investigated were:

1. Injection of CSM/LEM into lunar orbit and either
   - (a) retaining the LEM for redundant transearth propulsion capability
   - (b) detachment of the LEM while in lunar orbit, followed by its descent to pericynthion, ascent to the lunar parking orbit, rendezvous with the CSM, and return of the CSM to earth, or
   - (c) detachment of the LEM (unmanned) while in lunar orbit followed by its descent to the lunar surface with the CSM being returned to the earth, and
2. Circumlunar flights, with the abort velocity requirement at various points on the trajectory and the required velocity for certain terminal near-earth maneuvers being compared to the available spacecraft velocity.

All performance calculations were based on the use of the three spacecraft weight classes corresponding to the control weight gross weights for Saturn Apollo 501-503 (85,000 lbs.), 504 and 505 (93,000 lbs., due to removal of R & D Instrumentation), and 506 and subsequent (94,000 lbs.). A tabulation of the dry control weights and nominal propellant loadings as given in Reference 1 for the various spacecraft components at each of the three payload weight levels is given in Table 1.

BA-147B (8-64)

GROUP-4
Downgraded at 3 year intervals;
declassified after 12 years

This document contains information affecting the National Defense of the United States, within the meaning of the Espionage Laws, Title 18, U.S.C., Section 793 and 794, the transmission or revelation of which in any manner to an unauthorized person is prohibited by law.

Performance capabilities were also evaluated using distribution of propellant loading between the SM and LEM differing from the nominal values of Reference 1. The Apollo spacecraft allocated velocity budget utilized in this analysis for the various phases of the flight is presented in Table 2.

LUNAR ORBIT MISSION - CSM and LEM REMAIN ATTACHED

The entire spacecraft is injected into a free return translunar trajectory and is then transferred into a lunar orbit, 80 miles from the lunar surface. The CSM and LEM remain attached and after the specified orbital stay time are placed on a transearth trajectory. The primary purpose of keeping the LEM attached is to provide propulsion backup to the SM.

1. The capability of the LEM propulsion to provide a velocity increment sufficient to meet the transearth ΔV budget was determined. In the first example it was assumed that the SM was used during the translunar phase of the flight and for deboost into lunar orbit, but was inoperative on the return leg of the journey. The results indicated that the LEM is adequate as a backup propulsion system for departure from lunar orbit for the two heaviest gross spacecraft weights but does not provide enough ΔV for the 85,000 lb. payload with nominal propellant loading. In the latter case, however, additional off-loading of the SM propellant tanks by an amount ranging from 3200 to 4100 lbs., with addition of an equal weight of propellant to the LEM tanks, will insure that both the primary SM propulsion system and the backup LEM system possess sufficient ΔV capability to meet transearth requirements. A summary of the results obtained is presented in Section 1 of Table 3.

2. A tabulation of the available ΔV resulting from various sequential firing combinations of the SM, LEM Descent and LEM Ascent propulsion systems with the nominal propellant loadings is given in Section 2 of Table 3 for the three payload weight classes. The LEM stages are assumed to be jettisoned upon propellant depletion, and it is also assumed that the Descent Stage is jettisoned prior to ignition of the Ascent Stage.

Note that the use of the SM alone, even with its tanks fully loaded, does not meet the ΔV budget if the LEM is retained (Sections 2 and 4 of Table 3). Sequential firing of the SM and either the Descent or Ascent Stage is required, providing a ΔV capability which exceeds the spacecraft ΔV budget for all three spacecraft gross weights. The excess ΔV still remaining can be utilized for additional LEM propulsion systems tests and/or to reduce earth entry speed.

The conclusion from this is that if the LEM is retained for transearth backup, then it is necessary to use one of the LEM stages even if the SPS burn is successful.

3. An alternative mode of using the LEM to provide propulsion redundancy is to plan on using the Descent and Ascent Stages first for the transearth burn. Successful firing of these two stages provides more than enough ΔV; on SA-503, propellant must again be off-loaded from the SM and added to the LEM. This is the same as the previous example in which Descent and Ascent Stages are used only if the SPS fails. If either or both of these stages fails, then they are jettisoned and more than adequate ΔV is available from the SPS alone as shown in Section 3 of Table 3. In the event that the Descent and Ascent Stages perform nominally, the ΔV capability of the SPS propulsion system can be used to decelerate the vehicle just prior to reentry.

UNMANNED LUNAR LANDING OF LEM

A mission was considered in which a CSM/LEM is injected into a translunar trajectory and then placed into a lunar orbit by utilization of the SPS. The unmanned LEM is separated from the CSM and descends to the lunar surface. The CSM, after its designated stay time in lunar orbit, is returned to the earth.

Utilizing the nominal spacecraft weights, as given for each mission in Reference 1, it was found that the SPS had more than sufficient performance capability for the transearth portion of the mission for all three spacecraft weights, as shown in Section 1 of Table 4. However, in the case of the 85,000 lb spacecraft, it was necessary to off-load 2,730 lb

of LEM Ascent Stage propellant and add an equal weight of Descent Stage propellant in order that the Descent Stage possess sufficient ΔV to match the budgeted descent maneuvers in Table 2. It should be noted that even with this greater than nominal Descent Stage propellant load, the ultimate capacity of the stage is not closely approached.

The performance gain resulting from utilizing a full Block II SM (with Ascent Stage off-loaded to maintain a fixed gross payload weight) was also calculated and is shown in Section 2 of Table 4. Increases in available incremental velocity of 450 to 750 ft/sec are obtained in this case.

The maximum weight unmanned LEM that can be placed in lunar orbit was also determined. This calculation was based on the premise that the SM performance capability need only match the ΔV budget with the CSM chase requirement deleted. The maximum LEM weights obtained were 25,500 lb, 30,200 lb, and 30,600 lb depending on the gross spacecraft weight injected into the translunar trajectory. Thus, except on SA-503, it is possible to place a LEM, which is heavier than the present control weight of 29,500 lb, in lunar orbit, with no reduction in translunar and transearth ΔV requirements. If the LEM descent ΔV budget is reduced by, e.g., decreasing the flexibility allowances in the final approach and landing phases, it would, therefore, be possible to land a LEM which is heavier than the control weight. Reductions of about 235 ft/sec and 385 ft/sec are necessary for the gross payloads of 93,000 and 94,000 lbs, respectively. The increased weight could be utilized by providing additional LEM instrumentation. Alternatively, the CSM ΔV budget could be increased (and flight times decreased) if a control weight LEM is flown. These conclusions are shown, in a later section, to still be valid for a proposed higher LEM control weight of 32,000 lb and the accompanying reduced ΔV budget.

LUNAR ORBIT MISSION - LEM DESCENT TO PERICYNTHION, ASCENT TO LUNAR PARKING ORBIT, RENDEZVOUS AND RETURN

The spacecraft is injected into a translunar trajectory and is then subjected to a velocity increment which places it in lunar orbit. At a predetermined instant the LEM is separated from the SM and placed on an elliptical orbit with pericynthion at 50,000 ft. to allow one or more low passes over a proposed Apollo landing site. This is followed by rendezvous of the LEM with the CSM in the lunar parking orbit. Two types of elliptical orbits were considered, i.e., Hohmann and equiperiod. The former, of course, is the minimum energy requirement but has the important drawback of requiring a waiting time of approximately 40 hours

before the rendezvous can be effected. The equiperiod transfer, on the other hand, allows rendezvous once per orbit and requires only a comparatively modest increase in propellant consumption over the Hohmann transfer case. The ΔV budgets for both the Hohmann and equiperiod LEM maneuvers are given in Table 5.

After completion of the rendezvous of the LEM and CSM, the spacecraft is placed on a transearth trajectory. In determining the minimum incremental velocity requirements to insure mission completion, an allowance of 455 ft/sec was included for CSM rescue of the LEM in the lunar parking orbit, since it is presumed that the LEM would be manned. All of the data pertaining to the techniques discussed below for achieving this mission are given in Table 6.

One method of performing this mission is to use the SM propulsion system for the entire braking requirement into lunar orbit, as in the standard Apollo mission. The descent and ascent maneuvers are assumed to be accomplished by utilizing the Descent Stage. The tabulation of the available ΔV for the transearth phase of the flight for the various sequences of propulsion utilization is given in Section 1 of Table 6. In all tabulated cases utilizing either or both of the LEM stages, it was assumed that the CSM did not have to be used for LEM rescue, and this propellant allowance can therefore be utilized during the transearth burn. The SM alone provides enough ΔV to achieve the return of the CSM in all cases if the LEM is jettisoned prior to injection into the transearth trajectory. However, the incremental velocity available from the SM if the LEM remains attached, for propulsion backup, even with LEM propellants off-loaded (Section 3 of Table 6), is not sufficient to meet the ΔV budget for the transearth phase. However, utilization of the Descent Stage and/or Ascent Stage together with the SM will meet the mission requirements for both the Hohmann and equiperiod cases. Finally, it is seen that the LEM can provide enough ΔV to meet the transearth requirements and thus act as a backup system for departure from lunar orbit after either Hohmann or equiperiod transfers, except in the 85,000 lb. payload case. For the 85,000 lb. payload, off-loading of SPS so as to have its performance capability (with LEM jettisoned) just match the ΔV budget produces a substantial increase in LEM backup ΔV capability but still falls significantly short of meeting the required incremental velocity.

Another technique that could be used is one which results in the Descent Stage propellant tanks being empty at the completion of the descent to pericynthion maneuver. With the velocity requirement for the LEM descent phase known, the remainder of the Descent Stage performance capability is used in the final portion of the deboost into lunar orbit. An iterative procedure was used to determine how much SM propellant must be consumed in order to provide the first portion of the velocity requirement for achieving the lunar orbit injection. Ascent of the LEM to the lunar parking orbit and rendezvous with the CSM is performed employing the Ascent Stage, which then is utilized to its utmost capability to provide the initial velocity increment for the transearth phase of the flight. The remainder of the velocity needed to complete the mission is provided by the SM. Comparison of the increased ΔV using this method over that available using the preceding sequence indicates a 450 to 760 ft/sec (6 to 9 per cent) gain for Hohmann descent and ascent transfers and a 540 to 870 ft/sec (7 to 11 per cent) gain for equiperiod transfers.

CIRCUMLUNAR MISSION

The performance capabilities of the Apollo spacecraft propulsion systems during a circumlunar mission were evaluated. In the event of a successful translunar injection, a ΔV requirement of only about 600 ft/sec is imposed, 300 ft/sec for midcourse corrections on both the translunar and transearth phases of the flight. Consequently, a comparison of the available velocity increments corresponding to various sequences of propulsion system utilization with that required for abort during the flight at various points on the trajectory was made. Also, in the event of a successful mission the excess performance capability of the SPS could be utilized to decelerate the spacecraft prior to reentry instead of reentering at near-escape speed. The latter eventuality is also discussed. Data on the velocity increments required for abort were obtained from References 2 and 3. All of the performance data on the various sequences of propulsion utilization are given in Table 7.

The possibility of an abort from a nominal trajectory was the first problem investigated. Reasons for such an occurrence are, for example, environmental control system failure, material puncture of the spacecraft, presence of a solar flare resulting in a dangerous radiation level in earth-moon vicinity, etc. Figure 1 shows a comparison of the time from abort to reentry on various abort trajectories with the time to reentry on the nominal free return trajectory of Reference 3 as a function of the time of abort. Incremental abort velocities of 5000 ft/sec, 6500 ft/sec, and 8000 ft/sec were utilized in generating these abort trajectories.

The data of Figure 1 and Table 7 indicate that if the SPS can be used, the time to return to earth from midcourse can always be reduced substantially.

Aborts due to premature S-IVB cutoff will almost always result in the apogee taking place in the pre-lunar-sphere-of-influence region. For an abort in this region, the absolute minimum incremental velocity requirement is in the plane of motion of the vehicle. This minimum occurs very near the apogee of the pre-abort trajectory. Aborts with relatively low ΔV requirements (a maximum of about 500 ft/sec if S-IVB cutoff does not occur before one minute of the translunar injection burn is completed) will result in this case. The spacecraft performance capability far surpasses this value in almost every propulsion utilization sequence. However, the time interval between premature cutoff and reentry in this case could be of the order of several days in the worst case.

For minimum time aborts, the total time from premature cutoff to reentry is not likely to be less than an hour and need never be greater than 4 hours if as much as 10,000 ft/sec is available. This ΔV capability can be realized from the SM alone if the LEM is jettisoned prior to ignition. Figures 2 and 3 represent time to reentry as a function of premature cutoff time for minimum ΔV aborts and time critical aborts, respectively.

Aborts taking place within the moon's sphere of influence present two alternatives insofar as the mode of return is concerned, i.e., either direct return to the earth or free circumlunar return. Premature injection cutoff is not likely to result in an apogee within this region so that considerations are restricted to aborts from the nominal trajectory. Minimum ΔV aborts are those which circumnavigate the moon since they present no velocity requirement other than a small midcourse correction; however, they require relatively long return flight times. The incremental velocity required to reduce the return flight time compared to the nominal free return increases very sharply as the moon is approached (see Figure 4). The requirement is always greater than 5000 ft/sec once the boundary of the sphere of influence has been passed. The performance capabilities of the spacecraft, presented in Table 7, are adequate in most instances to return to the earth within a reasonable period of time providing the SM propulsion, at least, is operative. The use of LEM propulsion, in addition, or jettisoning of the LEM will provide an even more satisfactory method of meeting abort requirements.

If the circumlunar mission progresses satisfactorily, i.e., there is no need to initiate abort modes, then the relatively large velocity increments of Table 7, with a 600 ft/sec midcourse correction allowance reserved, can be used to reduce the spacecraft velocity prior to reentry or to achieve a near-earth orbit with a clear perigee so that a more favorable landing site may be selected or in order that additional CSM and LEM operations can be carried out.

Assuming that the vehicle returning from the circumlunar mission has a velocity of 35,000 ft/sec and makes an angle of six degrees with the horizontal at an altitude of 400,000 ft., the ΔV required to achieve a 100 NM circular orbit is about 10,000 ft/sec. Setting aside an additional 500 ft/sec velocity reserve for reentry from orbit, it is evident from Table 7 that a sequential firing of either the Descent or Ascent Stage with the SM is required to attain this circular orbit. Smaller values of available ΔV would result in higher apogee altitudes for the same 100 NM perigee altitude.

Figure 5 depicts a general curve relating available incremental velocity to the apogee altitude for a fixed perigee of 100 NM. The resulting apogee altitude for several of the propulsion utilization sequences are listed below:

	85000 lb Payload	93000 lb Payload	94000 lb Payload
	Apogee Altitude, NM		
SM, Descent Stage, Ascent Stage	650	100	100
SM (with LEM jettisoned)	450	450	390
SM (with LEM retained)	4730	6260	6040
SM, Descent Stage	1850	1300	1180
SM, Ascent Stage	2940	3250	3050

Alternatively, of course, if no "parking orbit" is necessary prior to entry, the spacecraft can simply be decelerated without changing the flight path angle. In this case, the entry velocity is just approximately 35,000 ft/sec minus the ΔV available from whichever propulsion sequence is utilized.

It should be kept in mind that these calculations are based upon impulsive ΔV's. In reality, gravity loss and finite burning time effects will be significant when decelerating near the earth due to low spacecraft thrust/weight ratio (as low as about .06 when using the Ascent Stage engine with a fully loaded Ascent Stage and CSM).

PERFORMANCE WITH INCREASED LEM WEIGHT

In anticipation of possible increases in the LEM control weight, sample calculations were performed considering the gross LEM weights to be 32,000 lb. The spacecraft ΔV budget for translunar and transearth phases of the mission under these conditions is as follows:

Translunar Phase (ΔV = 3607 ft/sec)

Main deboost	3440 ft/sec
Midcourse correction and allowances	167 ft/sec

Transearth Phase (ΔV = 3200 ft/sec, not including LEM rescue)

Main injection	3000 ft/sec
Midcourse corrections and allowances	200 ft/sec

The maximum LEM weight that can be placed in lunar orbit (or landed unmanned on the lunar surface, if the descent ΔV budget is reduced) is 33,000 lbs or 34,000 lbs for gross injected spacecraft weights of 93,000 and 94,000 lbs, respectively. Thus, deletion of the CSM chase and rescue ΔV again allows significant weight growth above the control weight for an unmanned LEM mission. Alternatively, if the LEM weight is held at 32,000 lbs, the CSM would have excess transearth ΔV capability of about 340 ft/sec and 650 ft/sec, respectively, in the two cases.

Use of the LEM propulsion systems as a backup for the SPS during the transearth burn from lunar orbit provides sufficient capability to meet the budgeted ΔV requirement. The incremental velocity available in the case of 94,000 lbs gross weight, e.g., is 4370 ft/sec compared with the required ΔV of 3200 ft/sec.

Therefore, it appears that the conclusions which were drawn on the basis of current control weights will not change if the LEM control weight is increased and the spacecraft ΔV budget is reduced in accordance with currently proposed revisions.

CONCLUSIONS

1. On circumlunar missions, the SPS capability is adequate to decelerate the CSM to approximately 25,000 ft/sec prior to reentry, either entering directly or first going into a low altitude parking orbit. Alternatively, if an abort situation arises any time during the flight, the spacecraft propulsion capability can be used to substantially reduce the time of flight to reentry as compared to continuing on the free circumlunar trajectory.

2. For lunar orbit missions, the LEM can be used to provide propulsion redundancy for the transearth injection phase. However, if the LEM is retained (rather than jettisoned prior to the transearth burn) as a backup to the SPS, then the SPS alone cannot meet the transearth ΔV requirement and either the Descent or Ascent Stage of the LEM must also be used. An alternative is to consider the LEM as the primary propulsion for the transearth burn with the SPS as backup. In this case, the two LEM stages provide sufficient ΔV if they both work. If one or both stages cannot be used, then the LEM is jettisoned and the SPS by itself has sufficient ΔV capability.

3. A lunar orbit mission can include manning the LEM and descending on an elliptical transfer orbit to a pericynthion altitude of 50,000 ft. in order to make one or more passes over a proposed Apollo landing site and/or to practice rendezvous operations under realistic conditions. Following rendezvous, there would still be enough propellant left for the LEM to provide propulsion redundancy for the transearth burn, except on SA-503 (85,000 lb payload).

4. On SA-504 and on, a fully loaded unmanned LEM can be landed on the moon with more than enough propellant remaining in the CSM for the transearth burn. Assuming that the CSM chase and rescue ΔV requirement is eliminated, this performance margin could be utilized in the form of extra transearth ΔV to reduce flight time.

5. Alternatively, retaining the nominal CSM ΔV budget (except for eliminating chase and rescue), an overweight LEM can be placed in lunar orbit. If the LEM descent ΔV budget can be reduced, e.g., by reducing the allowance for hover and

translation, then the overweight LEM can be landed on the moon. The additional weight capacity might be utilized by additional instrumentation.

6. On SA-503, however, (assuming an 85,000 lb payload) the LEM must be off-loaded.

7. Sample calculations indicate that the preceding conclusions, although based on a LEM control weight of 29,500 lbs, also hold for an increased LEM control weight with the correspondingly reduced ΔV budget currently being considered.

T. R. Kornreich

1021-TRK-jld

Attached
Tables 1-7, Figures 1-5, References

Copy to
Messrs. J. K. Holcomb - NASA/MAO
T. A. Keegan - NASA/MA-2

T. F. Baker - MSC/PL
F. W. Casey, Jr. - MSC/PS6
C. Huss - MSC/FM
C. Perrine - MSC/PS3
T. Skopinski - MSC/FM
K. L. Turner - MSC/PT5

J. W. Cremin - MSFC/R-AERO-DA
E. D. Geissler - MSFC/R-AERO
J. B. Winch - MSFC/R-AERO-DA

D. R. Anselmo
B. F. Brown
J. O. Cappellari
M. W. Cardullo
J. P. Downs
R. D. Hagner
P. L. Havenstein
W. G. Heffron
J. J. Hibbert
J. A. Hornbeck
B. T. Howard
M. W. Hunter II
D. B. James
B. Kaskey
P. R. Knaff
J. Z. Menard
C. R. Moster
V. S. Mummert
B. G. Niedfeldt
T. L. Powers
I. M. Ross
J. J. Schoch
P. F. Sennewald
R. V. Sperry
W. Strack
T. H. Thompson
J. M. Tschirgi
D. R. Valley
A. A. Vanderveen
R. L. Wagner
Central File
Security
Department 1023

REFERENCES

1. Control Weights Requirements (U), September 16, 1964, Office of Manned Space Flight, NASA (CONFIDENTIAL).

2. Bellcomm Report - Reference No. 64-2012 - "Preliminary Report on Apollo Abort Trajectories (U)", April 8, 1964 (CONFIDENTIAL).

3. MSFC Report - MTP-AERO-62-55, "Abort from a Coplanar Circumlunar Orbit" by N. J. Braud, June 29, 1962.

TABLE 1
APOLLO SPACECRAFT CONTROL WEIGHTS
SATURN V MISSIONS (Ref. 1)

	Injected Spacecraft Weight, lb		
	85000 lb	93000 lb	94000 lb
CM (with crew)	11000	11000	11000
SM:			
Injected Inert Weight	10200	10200	10200
Usable Propellant	38510	38510	39500
LEM Ascent Stage:			
Injected Inert Weight	4650	4650	4650
Usable Propellant	4325	5065	5065
LEM Descent Stage:			
Injected Inert Weight	3865	3865	3865
Usable Propellant	8650	15920	15920
Adapter - Total Weight	3800	3800	3800

Note: (1) Maximum capacity of the propellant tanks for the spacecraft propulsion systems are

SM	Block II	41000 lb
LEM	Descent Stage	15920 lb
LEM	Ascent Stage	5252 lb

TABLE 2
APOLLO SPACECRAFT ΔV BUDGET
FOR CONTROL WEIGHTS IN TABLE 1

Mission Phase	ΔV ft/sec
Translunar	
Braking into Lunar Orbit (including allowances)	3400
Midcourse Correction, Guidance Requirements, etc.	470
LEM Descent	
LEM Separation & Descent Transfer Orbit Injection	105
Initial Deboost	6130
Landing Maneuver	1150
LEM Ascent	
Launch to 50,000 ft.	6260
Ascent Transfer Orbit Injection	113
Midcourse, Rendezvous, Docking	273
Transearth	
CSM Rescue of LEM	455
Main Injection	3000
Midcourse Correction & Allowances	460

TABLE 3
APOLLO SPACECRAFT PERFORMANCE CAPABILITIES FOR LUNAR ORBIT MISSION
WITH CSM AND LEM ATTACHED

	Gross Payload 85000 lb	Gross Payload 85000 lb (Off-loaded SM)*	Gross Payload 93000 lb	Gross Payload 94000 lb
Sequence of Propulsion Utilization		Velocity Increment Available ft/sec		
1. Evaluation of LEM Propulsion as backup for SPS for transearth portion of mission. Assume SPS has satisfactorily provided injection into lunar orbit.		Transearth Requirement 3460 ft/sec		
a. Descent Stage, Ascent Stage (Descent Stage inert weight jettisoned after propellant depletion)	2700	3460-3700	4250	4200
b. Descent Stage	1650	2120-2300	3000	2950
c. SM (with LEM attached)	2630	2140-2340	1830	1930
2. CSM is returned; Descent Stage is jettisoned prior to ascent stage utilization		Mission Requirement 7330 ft/sec		
a. SM, Descent Stage, Ascent Stage	10200	10200	11150	11250
b. SM	6500	5600-5800	5700	5800
c. SM, Descent Stage	8700	8400	9350	9500
d. SM, Ascent Stage	7650	7400-7600	7450	7600

*The SM Propellant tanks are off-loaded, relative to nominal loadings of Reference 1, with an equal weight added to the LEM tanks, such that both the SPS (without LEM attached) and LEM propulsion system at least match the transearth ΔV requirements. The weight of propellant off-loaded consistent with the preceding requirement ranges from approximately 3200 to 4100 lbs.

CONFIDENTIAL
BELLCOMM, INC.
CONFIDENTIAL

TABLE 3

	Gross Payload 85000 lb	Gross Payload 85000 lb (Off-loaded SM)*	Gross Payload 93000 lb	Gross Payload 94000 lb
3. Utilization of LEM Propulsion as primary system departure from lunar orbit. SPS already used for de-boost into lunar orbit and now considered as backup for trans-earth portion of flight		Transearth Requirement 3460 ft/sec		
a. Descent Stage, Ascent Stage	2700	3460-3700	4250	4200
b. Descent Stage, Ascent Stage, SM	7400	7160-7250	8150	8250
c. Ascent Stage, SM	5750	4870-5130	5200	5300
d. SM (with entire LEM jettisoned)	4750	3490-3770	3900	4050
4. Off-load LEM propellant tanks such that SM tanks are fully loaded; Descent Stage inert weight jettisoned immediately after propellant depletion		Mission Requirement 7330 ft/sec		
a. SM	7100	--	6200	6100
b. SM, Descent Stage, Ascent Stage	10250	--	11100	11250
c. SM (with entire LEM immediately jettisoned)	9750	--	9750	9750

*The SM Propellant tanks are off-loaded, relative to nominal loadings of Reference 1, with an equal weight added to the LEM tanks, such that both the SPS (without LEM attached) and LEM propulsion system at least match the transearth ΔV requirements. The weight of propellant off-loaded consistent with the preceding requirement ranges from approximately 3200 to 4100 lbs.

BELLCOMM, INC.
CONFIDENTIAL
CONFIDENTIAL

TABLE 4

APOLLO SPACECRAFT PERFORMANCE CAPABILITIES FOR LANDING UNMANNED LEM ON THE LUNAR SURFACE

	Gross Payload 85000 lb	Gross Payload 93000 lb	Gross Payload 94000 lb
Sequence of Events to Perform Mission	Velocity Increment Available for Transearth Phase, ft/sec		
1.* SM Propulsion provides velocity needed for injection into lunar orbit, midcourse correction and allowances (3870 ft/sec)	Transearth Velocity Requirement 3460 ft/sec		
Unmanned LEM Descends to Lunar Surface; CSM returns to earth via SM Propulsion;			
SM Transearth Capability	4750	3900	4050
LEM Gross Weight	21500 lb.	29500 lb.	29500 lb.
2. SM Block II Propellant Tanks filled to capacity: LEM Ascent Stage is off-loaded; Same sequence as 1.	Transearth Velocity Requirement 3460 ft/sec		
SM Block II Transearth Capability	5450	4650	4500
LEM Gross Weight	19000 lb.	27000 lb.	28000 lb.
3. Heaviest LEM that can be left in lunar orbit (or landed unmanned on the moon with reduced descent ΔV budget)	25500 lb.	30200 lb.	30600 lb.
SM Transearth Capability	3460 fps	3460	3460
Reduction in LEM descent ΔV budget	--	235 fps	385 fps

*The gross CSM & LEM weights were the same as the nominal values of Reference 1 but to insure that Descent Stage ΔV matched the budgeted ΔV for descent maneuver for 85000 lb payload it was necessary to off-load 2730 lb of Ascent Stage Propellant & add 2730 lb of Descent Stage Propellant.

BELLCOMM, INC.

CONFIDENTIAL

CONFIDENTIAL

TABLE 5

ΔV BUDGET FOR LEM DESCENT TO PERICYNTHION, ASCENT TO LUNAR PARKING ORBIT AND RENDEZVOUS WITH CSM

	ΔV, ft/sec for Hohmann Transfer Trajectories	ΔV, ft/sec for Equiperiod Transfer Trajectories
Descent Phase		
LEM Separation and Descent Transfer Orbit Injection	105	375
Ascent Phase		
Midcourse	50	50
Rendezvous	105	375
Docking	25	25
TOTAL ASCENT PHASE	180	450

TABLE 6

APOLLO SPACECRAFT PERFORMANCE CAPABILITIES FOR LUNAR ORBIT MISSION INCLUDING LEM DESCENT TO PERICYNTHION, ASCENT TO PARKING ORBIT AND RENDEZVOUS WITH CSM

	CONTROL WEIGHT SPECIFICATIONS			
	GROSS PAYLOAD 85000 lb.	GROSS PAYLOAD 93000 lb.	GROSS PAYLOAD 94000 lb.	GROSS PAYLOAD 85000 lb.*
Sequence of Events to Perform Mission	Velocity Increment Available for Transearth Phase, ft/sec			
1. Assume SPS has satisfactorily provided injection into lunar orbit;	Transearth Velocity Requirement is 3460 ft/sec			
a. Hohmann descent transfer of LEM to pericynthion via Descent Stage; Hohmann ascent transfer of LEM to parking orbit and rendezvous with CSM via Descent Stage. Departure from lunar orbit using one of the following sequences:				
SM (LEM attached)	2700	1850	1950	2700
**SM (LEM jettisoned)	4300	3500	3700	3460
Descent Stage, Ascent Stage, SM	7310	8050	8310	--
Descent Stage, Ascent Stage	2560	4100	4160	3280
Descent Stage, SM	6280	6770	7020	--
Ascent Stage, SM	5780	5240	5440	--
SM, Ascent Stage	3730	3140	3260	--
SM, Descent Stage	4230	4670	4840	--
b. Equiperiod descent transfer of LEM to pericynthion via Descent Stage; Equiperiod ascent transfer of LEM to parking orbit and rendezvous with CSM via Descent Stage. Departure from lunar orbit using one of the following sequences:				

*The SM propellant tanks are off-loaded, relative to nominal loadings of Reference 1, with an equal weight added to the LEM tanks such that the SPS (without LEM attached) just matches the ΔV requirements. This corresponds to 2760 lb. of off-loaded propellant.

**In addition to CSM rescue of LEM.

CONFIDENTIAL
BELLCOMM, INC.
CONFIDENTIAL

TABLE 6

	CONTROL WEIGHT SPECIFICATIONS			
	GROSS PAYLOAD 85000 lb.	GROSS PAYLOAD 93000 lb.	GROSS PAYLOAD 94000 lb.	GROSS PAYLOAD 85000 lb.*
SM (LEM attached)	2750	1900	2000	2750
**SM (LEM jettisoned)	4300	3500	3700	3460
Descent Stage, Ascent Stage, SM	7130	7800	7980	--
Descent Stage, Ascent Stage	2380	3850	3830	3090
Descent Stage, SM	6100	6520	6690	--
Ascent Stage, SM	5780	5240	5440	--
SM, Ascent Stage	3780	3200	3310	--
SM, Descent Stage	4090	4490	4540	--
2. SM provides initial portion of lunar orbit injection velocity requirement; Descent Stage provides remainder of this requirement such that after descent to pericynthion, Descent Stage propellant tanks are empty; Ascent Stage provides ascent to lunar orbit, rendezvous with CSM and first portion of transearth ΔV; SM provides remainder of transearth ΔV.		Transearth Velocity Requirement 3460 ft/sec		
a. Total Transearth Capability where descent to pericynthion and ascent to lunar orbit are Hohmann transfer trajectories	7760	8810	8920	
Ascent Stage	830	880	880	
SM	6930	7930	8040	
b. Total Transearth Capability where descent to pericynthion and ascent to lunar orbit are equiperiod transfer trajectories	7670	8700	8850	
Ascent Stage	820	850	860	
SM	6850	7850	7990	

*The SM propellant tanks are off-loaded, relative to nominal loadings of Reference 1, with an equal weight added to the LEM tanks such that the SPS (without LEM attached) just matches the ΔV requirements. This corresponds to 2760 lb. of off-loaded propellant.

**In addition to CSM rescue of LEM.

BELLCOMM, INC.
CONFIDENTIAL
CONFIDENTIAL

TABLE 6

	CONTROL WEIGHT SPECIFICATIONS			
	GROSS PAYLOAD 85000 lb.	GROSS PAYLOAD 93000 lb.	GROSS PAYLOAD 94000 lb.	GROSS PAYLOAD 85000 lb.*
3. SM propellant tanks filled to capacity; LEM propellant off-loaded; Same sequence as 1.;	Transearth Velocity Requirement 3460 ft/sec			
a. Hohmann maneuvers				
SM (LEM attached)	3300	2400	2300	
**SM (LEM jettisoned)	5000	4250	4250	
b. Equiperiod maneuvers				
SM (LEM attached)	3350	2450	2350	
**SM (LEM jettisoned)	5000	4250	4250	

*The SM propellant tanks are off-loaded, relative to nominal loadings of Reference 1, with an equal weight added to the LEM tanks such that the SPS (without LEM attached) just matches the ΔV requirements. This corresponds to 2760 lb. of off-loaded propellant.

**In addition to CSM rescue of LEM.

BELLCOMM, INC.
CONFIDENTIAL
CONFIDENTIAL

TABLE 7

APOLLO SPACECRAFT PERFORMANCE CAPABILITIES FOR CIRCUMLUNAR MISSIONS

	Gross Payload 85000 lb	Gross Payload 93000 lb	Gross Payload 94000 lb
Sequence of Propulsion Utilization	Velocity Increment Available* ft/sec		
1. SM (no jettisoning of LEM)	5900	5100	5200
2. Inert weight of Descent and Ascent Stages is jettisoned immediately after propellant depletion of each stage, respectively			
a. Descent Stage, Ascent Stage, SM	11550	12500	12600
b. SM, Descent Stage, Ascent Stage	9600	10550	10650
c. Ascent Stage, SM	10550	10650	11600
d. SM, Ascent Stage	7050	6850	7000
e. Descent Stage, Ascent Stage	1150	2050	2050
f. Descent Stage, SM	11000	11800	11900
g. SM, Descent Stage	8100	8750	8900
h. SM (LEM jettisoned)	9900	9900	10000

*After allowance of 600 ft/sec for midcourse corrections.

BELLCOMM, INC.
CONFIDENTIAL
CONFIDENTIAL

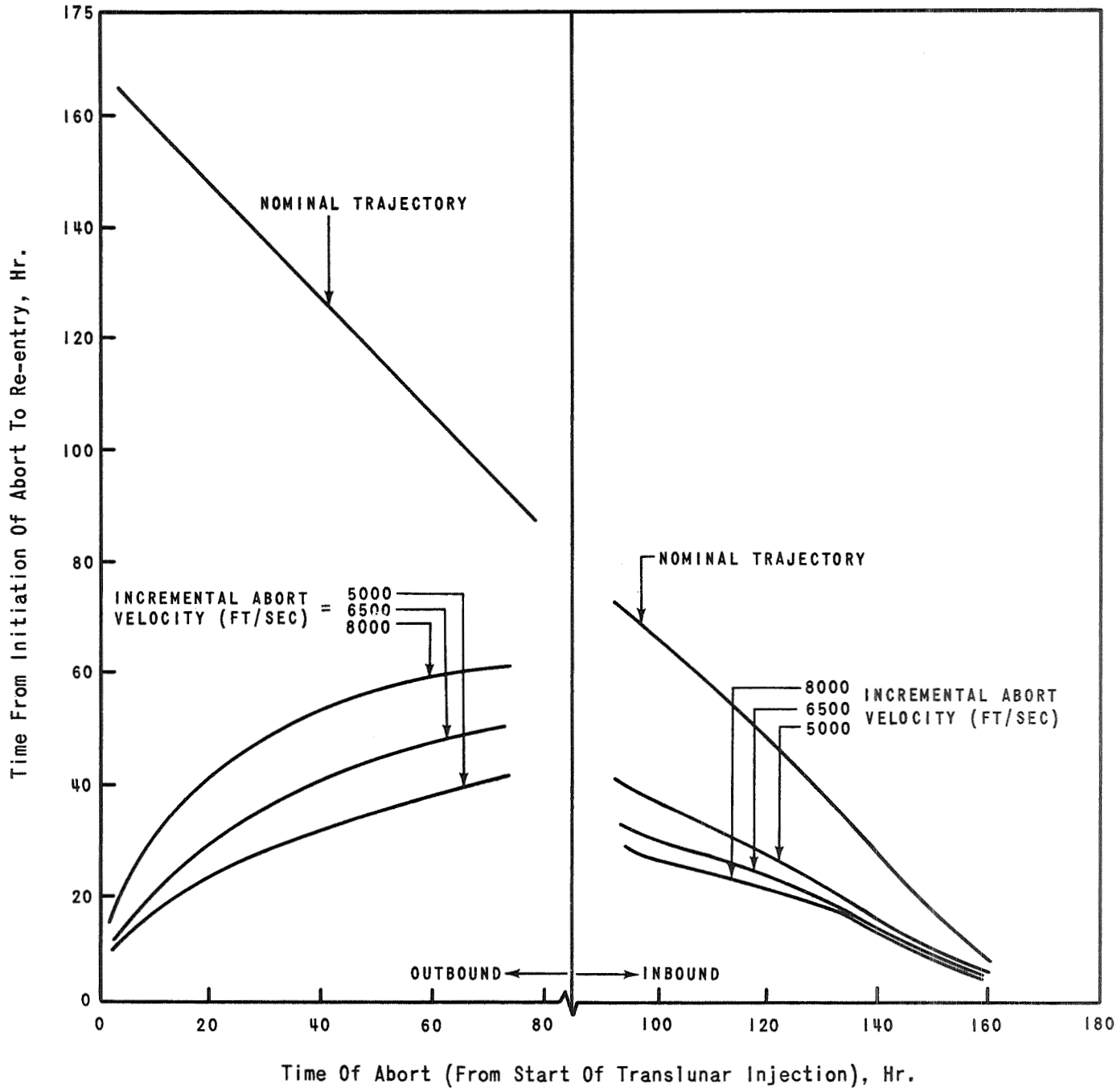

FIGURE 1 TIME FROM INITIATION OF ABORT TO RE-ENTRY VS TIME OF ABORT FROM NOMINAL TRAJECTORY

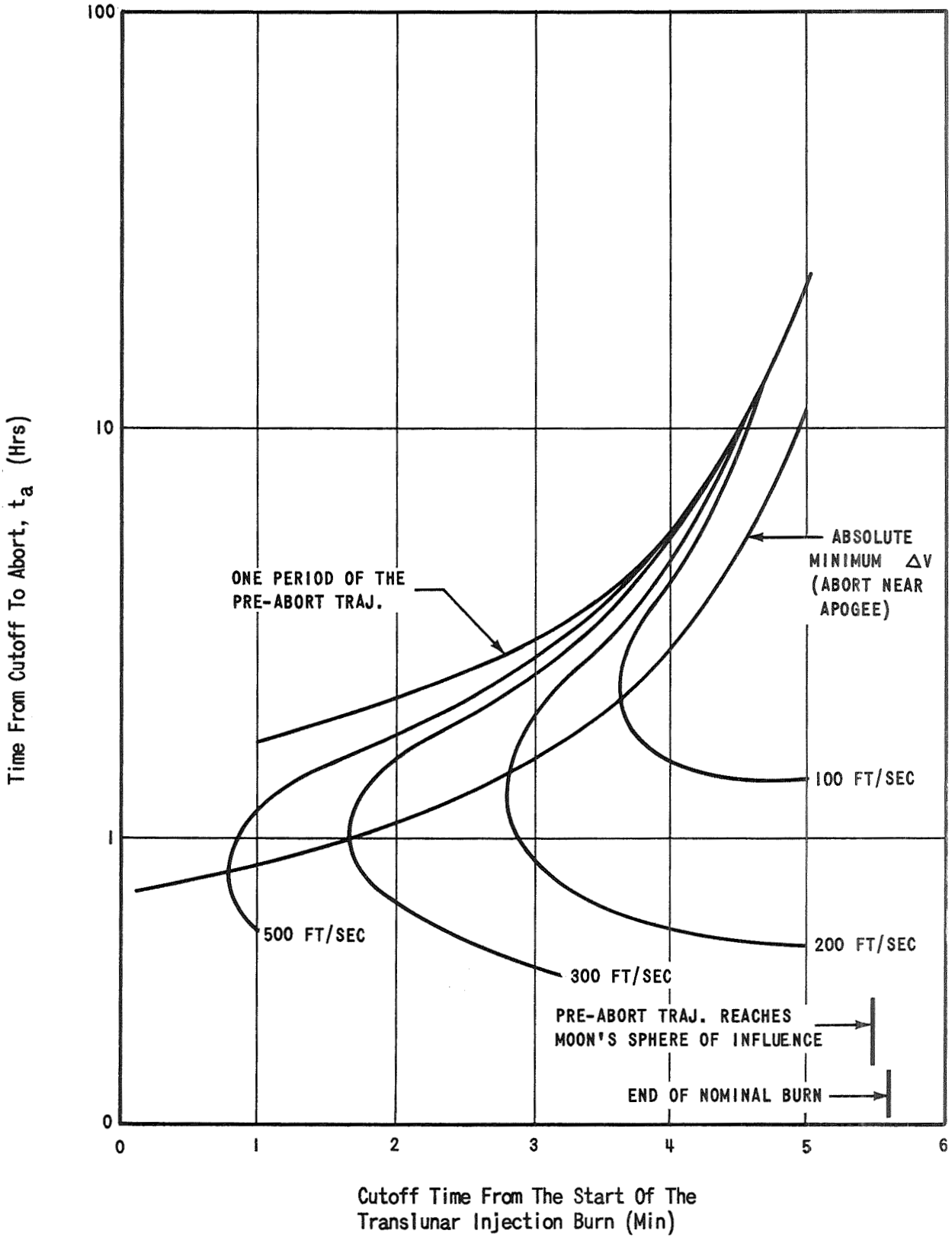

FIGURE 2 TIMES FROM CUTOFF TO ABORT FOR MINIMUM ΔV, IN-PLANE ABORTS (SINGLE IMPLUSE ABORT)

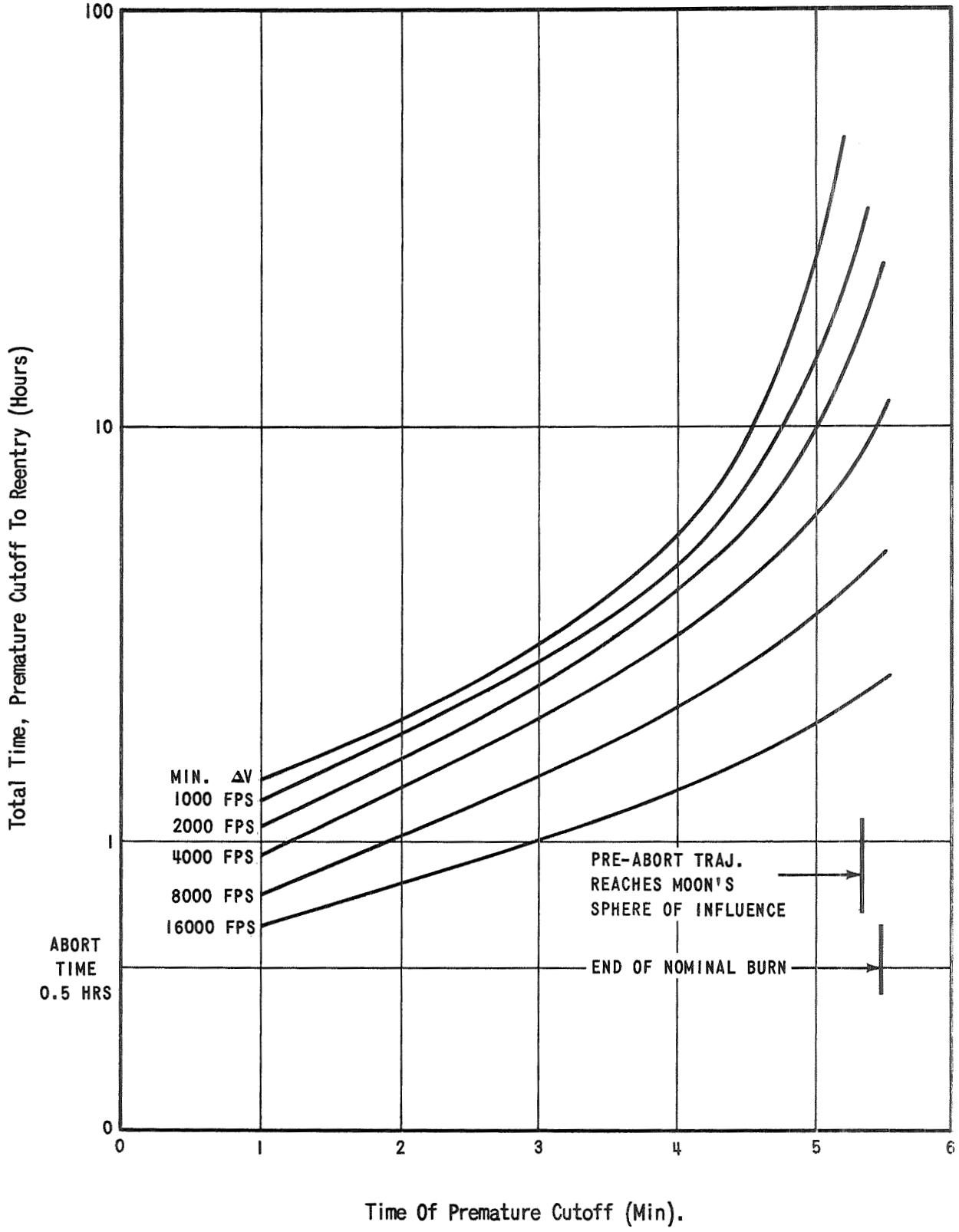

FIGURE 3 TOTAL TIME FROM PREMATURE CUTOFF TO REENTRY FOR IN-PLANE, TIME CRITICAL ABORTS (ABORT 30 MIN FOLLOWING CUTOFF)

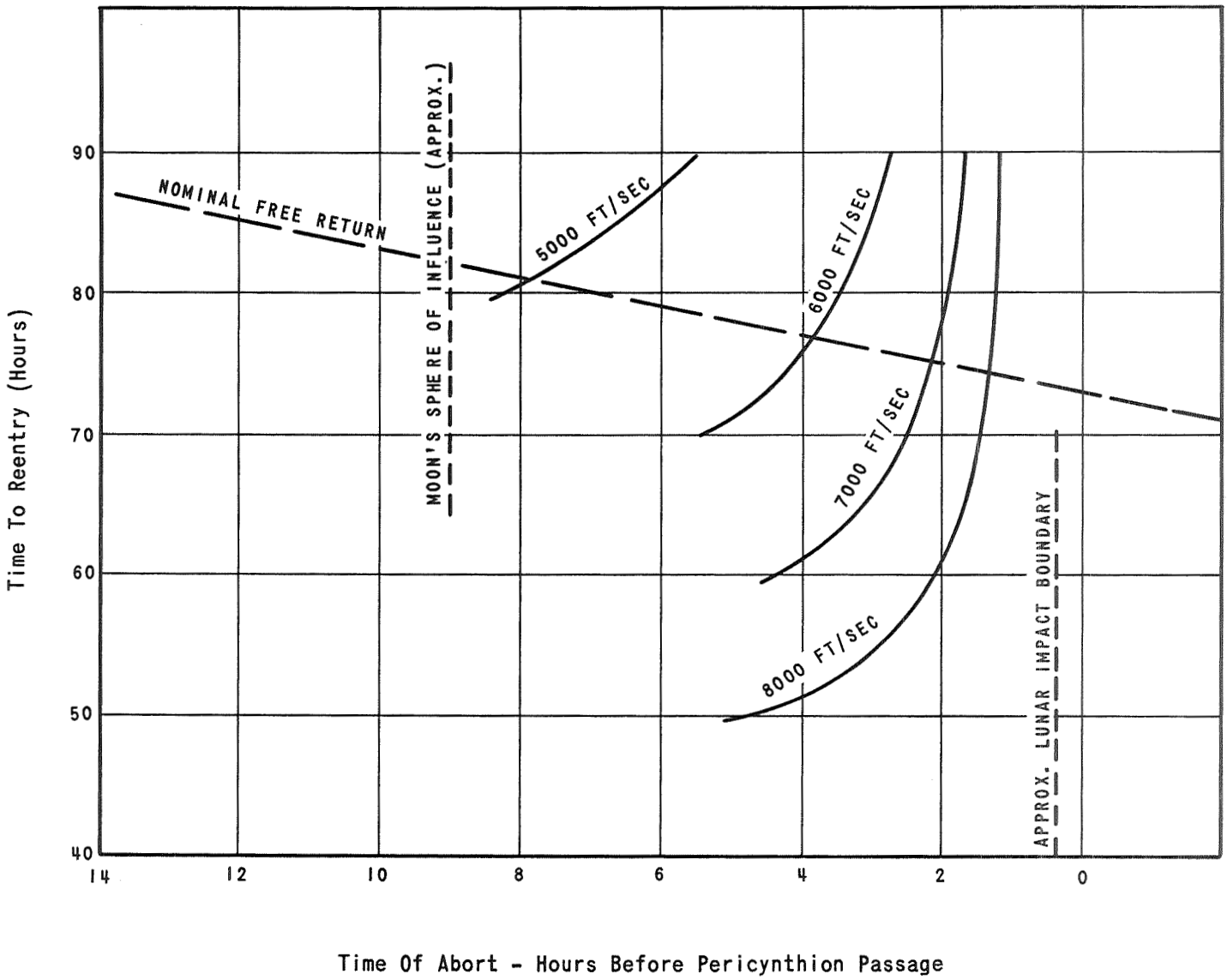

FIGURE 4 DIRECT RETURN TO EARTH ABORTS FROM THE NOMINAL TRANSLUNAR TRAJECTORY (WITHIN THE MOON'S SPHERE OF INFLUENCE)

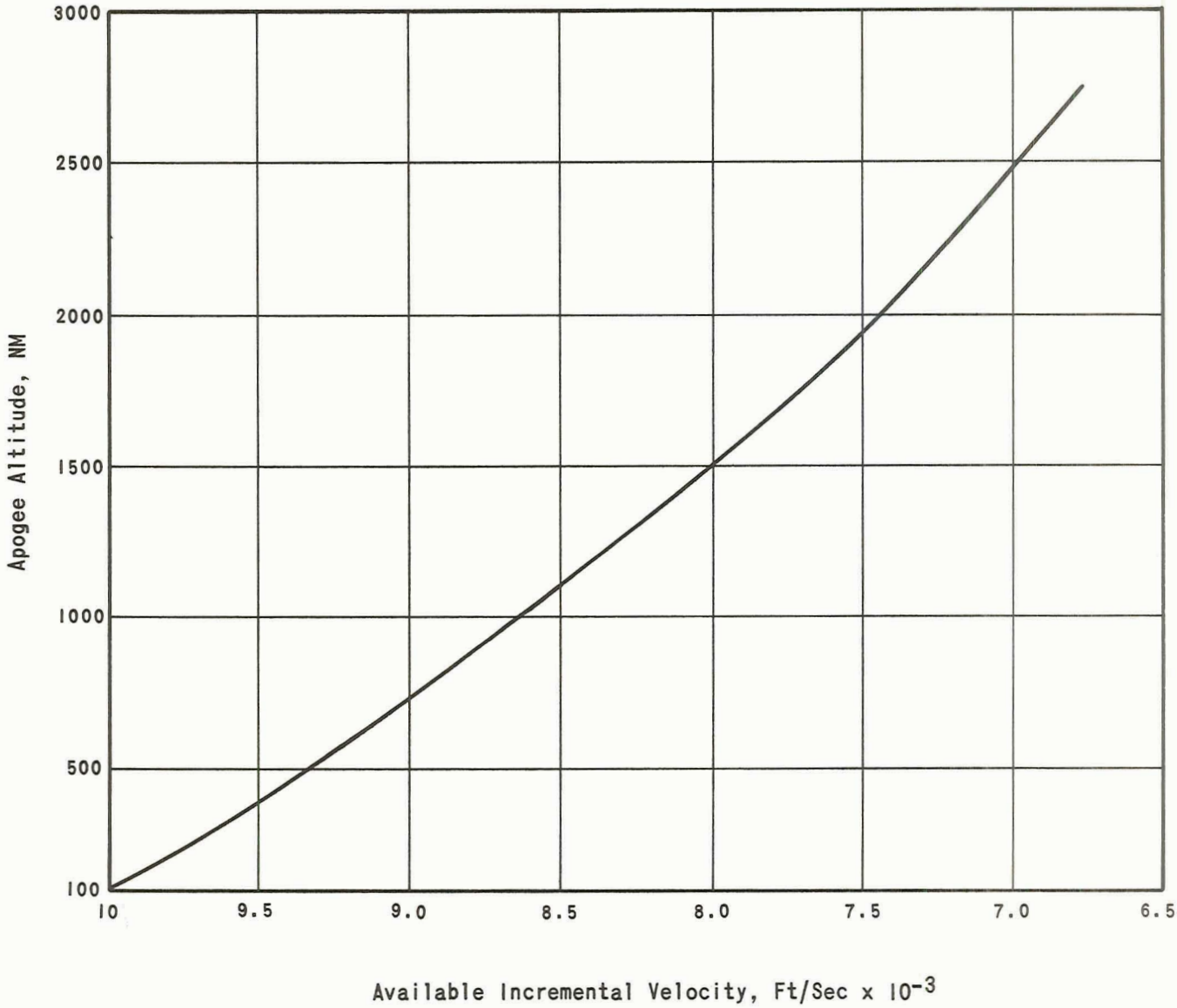

FIGURE 5 AVAILABLE INCREMENTAL VELOCITY VS APOGEE ALTITUDE FOR PERIGEE OF 100 NM

CONFIDENTIAL

CONFIDENTIAL